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Participatory selection of sustainability criteria and indicators for bioenergy developments

Thomas Kurka*, David Blackwood

University of Abertay Dundee, Bell Street, Dundee, Angus DD1 1HG, Scotland

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ABSTRACT

This paper presents a generic approach for selecting sustainability criteria and indicators (C&I) by using a participatory methodology. Selecting appropriate C&I to assess the sustainability of projects or developments is crucial and significantly influences the assessment results. The methodology, which consists of two processes: a pre-selection of suitable C&I by the researchers and a final selection by regional bioenergy experts in a multi-stakeholder forum, was applied in a Scottish region (Tayside & Fife).

The paper concludes that the methodology provides a transferable approach to systematically select C&I and to justify this selection. Furthermore, the pre-selected and final C&I for the case study can serve as a benchmark set and starting point for similar decision making situations in other regions. In order to provide a wide application potential for the bioenergy field, the case study took account of a range of scenarios and alternatives. Moreover, the identified C&I and requirements for selection from literature provide a broad application potential to assist C&I selection, as they cover the sustainability field in general, the energy sector and the bioenergy sector in particular.

Contents

* Corresponding author. Tel.: +44 1382 308545; fax: +44 1382 308117.
E-mail addresses: t.kurka@abertay.ac.uk, t.kurka@gmx.de, t514597@abertay.ac.uk (T. Kurka).

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1. Introduction

This paper presents a methodology for participatory selection of criteria and indicators (C&I) for bioenergy developments. The methodology was applied in a case study area in Scotland (Tayside and Fife). Sheppard and Meitner [1] and others [2–4] highlight that C&I reflect issues of concern of stakeholders and experts of an industry and can be used to measure and communicate the sustainability of projects or progress on sustainable development. In the 'Guidelines for Applying Multi-Criteria Analysis to the Assessment of Criteria and Indicators' [5], C&I are stratified into four levels. The first level comprises of a principle, which is described as a "fundamental truth or law as the basis of reasoning or action". Principles justify the chosen criteria, indicators and verifiers. On the second level, a criterion is defined as a "principle or standard that a thing is judged by". Criteria enhance the meaning and operability of principles, however do not measure performance. On the third level, an indicator is described as a variable or component "used to infer the status of a particular criterion". Indicators are comprised of specific information about a criterion, and can be measured by verifiers, which are defined as "data or information that enhances the specificity or the ease of assessment of an indicator" [5] (p.11 et seq.). Waage et al. [6] and Madlener et al. [7] use a similar hierarchy by describing that criteria are operationalized with indicators. For example, the criterion 'climate change' can be operationalized by the indicator 'CO_2 equivalent emissions'. However, in literature about decision making it can be observed that the term 'indicator' is sometimes synonymously used with 'criterion' and vice versa [8,9].

Vera [3] stress that if taken together C&I can provide an overview of the whole energy system, including interlinkages and trade-offs among various aspects of sustainable development, as well as long-term implications of current decisions and behaviors. Progress or lack of it towards sustainable development can be measured by observing changes in C&I values over time [10], which allows the carrying out of focused measures for improvement to avoid adverse effects in specific areas, if required. Furthermore, they can be appropriate tools for communicating and promoting dialogue with respect to energy issues related to sustainable development to stakeholders, policymakers and the public [3]. Additionally, Olsthoorn et al. [11] point out that the high complexity level of an issue, for instance the natural environment, demands the need of appropriate C&I. The selection of appropriate C&I is crucial to assess a project or development, because this choice significantly influences the results of an assessment [12]. Therefore, it was emphasized that in the sustainability context, C&I selection becomes a "delicate process of translation from socio-environmental agreements to specific observed properties of a complex system" [13] (p. 2562), and that the chosen C&I are the result of the social and political framework at a particular period in history [14].

In this paper a methodology for participatory selection of C&I for bioenergy developments is described. The methodology was also applied in the mentioned case study area (Tayside & Fife). First, literature on methodologies to select C&I for decision-making in the sustainability assessment field in general, as well as the energy and bioenergy fields in particular, was reviewed. Then, an appropriate methodology for participatory C&I selection was carried out starting with identifying C&I from literature against which sustainability in the bioenergy and the wider energy sector have previously been assessed. This was followed by the identification and discussion of requirements to select appropriate C&I from literature. Based on these two generic steps, the methodology was specifically applied in the case study area, which involved multiple steps. First, scenarios and alternatives were developed. Second, most suitable requirements for C&I selection for the case study were determined. Then, the sustainability C&I identified from literature were pre-selected in accordance with the determined requirements. The next step was to present the resulting short-list of C&I to identified bioenergy experts for discussion in a multi-stakeholder forum. In this forum the participants were asked to reach a consensus on the most suitable C&I for the case study by taking account of the same requirements for selection as in the pre-selection process. In this paper, the results of the application of the participatory C&I selection methodology are also discussed before conclusions are drawn.

2. Methodology for participatory C&I selection

In this section methodologies to select C&I for decision-making in the sustainability field and the energy and bioenergy sectors from relevant literature are briefly described. In general, Starkl and Brunner [15] recommend that integrative assessments of sustainability should not be based on prescribed or standardized C&I and rather be specifically selected on a case to case basis. Due to the sheer volume of C&I, which can be found in literature, several authors of academic papers propose to identify and pre-select C&I based on relevant literature, followed by a process of verification and/or refinement by stakeholders [1,16,17]. Gilmour et al. [18] followed this approach and additionally developed new case-specific C&I. First, the C&I pre-selection process took place. Then, key stakeholders were individually interviewed to verify and refine pre-selected C&I. In this process stakeholders were asked to take account of the specific drivers, aspirations and objectives of the development. In addition to the interviews a document analysis to refine and verify potential indicators, as well as to identify associated data availability was undertaken.

Sheppard and Meitner [1], Gilmour et al. [18] and Graymore et al. [16] suggest using C&I or selection frameworks, which are specific to a country or region and/or which are well-established in the industrial sector. For instance, in Graymore et al. [16], a project undertaken in South-West Victoria (Australia) is described, for which a set of C&I applicable for tracking progress towards sustainable development was identified. First, they identified a vast array of C&I already in use for measuring sustainability at a global, regional and local scale through an extensive literature review. Using this 'global' set of C&I a 'filtering' process' was carried out to refine the C&I set by involving stakeholders representing regional organizations and communities from their case study area.

Following the methodology recommendations from the reviewed literature, the methodology presented in this paper consisted of both, generic and case-study specific parts. First, C&I from literature were identified against which sustainability in the bioenergy and the wider energy sectors have previously been assessed (Section 2.1). Then, requirements to select appropriate C&I from literature were identified (Section 2.2). Based on these two generic steps, the methodology was specifically applied in the case study area involving the main steps: development of scenarios and alternatives (Section 3.1), selection of requirements for C&I selection (Section 3.2), C&I pre-selection by the researchers (Section 3.3) and final C&I selection by regional bioenergy experts (Section 3.4). In the subsequent sections these processes are described and discussed in detail.

2.1. Identification of sustainability C&I in literature

Employing C&I for decision making has been extensively addressed in academic papers and other publications covering the sustainability assessment field in general, as well as the energy and bioenergy fields in particular. In Table 1C&I from reviewed literature are summarized. In general, it can be observed that C&I in literature are either grouped into the broad categories of social, economic and environmental [2,19–22] or an additional forth aspect (technical) is common to evaluate energy systems or scenarios in particular [7,9,12,17,23,24].

Table 1
Summary of C&I identified in literature.

C&I related to:	Source:
Environmental C&I:	
NO_x emissions	[20,24,27,30–33]
Air quality or other non-GHG emissions (e.g. CO emissions, SO_2 emissions, particles emissions)	[3,7,8,12,17,19,24,31]
CO_2 emissions	[8,12,17,20,24,26,27,30,32–38]
GHG emissions or climate change (e.g. total carbon savings)	[3,9,19,25,31,39]
Land take, use or requirement, land use change or effective land use	[12,24,38,40]
Direct or indirect land conversion caused by biofuel plantation (e.g. visual impacts, quality of landscape, effects on biodiversity and ecosystems, species protection, deforestation, soil quality and protection, crop management and agrochemical use)	[3,7,9,17,19,39]
Ecological justice	[7,17]
Adaptability	[7,17]
Noise	[7,17,19,24,41]
Water consumption	[9,12,38]
Water management or quality	[3,7,17,19,39]
Waste generation or management	[3,18,19,39,41,42]
Rational use of resources or natural resource efficiency	[7,8,17,19]
Economic C&I:	
Investment costs	[8,12,18,20,24,25]
Operational or maintenance costs	[7,8,17,20,24,38]
Costs and economic viability (e.g. net present value (NPV), payback periods, life cycle cost, microeconomic sustainability)	[19,24,25,37,40]
Energy prices/costs for end-users	[3,9,20,24]
Macroeconomic sustainability, economic development, stability, benefit or output, balance of trade or payments	[17,19,39,40]
Technological advantage or diversification of technologies	[3,7,17]
Resources or fuel availability or import dependency (e.g. import dependency, resource availability, regional self-determinacy, energy security, reliability of electricity supply)	[3,7,9,12,17,38,40,43]
Technical C&I:	
Efficiency	[3,8,9,12,20,24–29,38]
Health or safety of energy systems	[3,24,39]
Maturity or knowledge level of the energy generation technology in use	[24,25,34,35]
Reliability of energy systems as well as their technological capability and limitations	[24,28,30,44]
Electricity generation potential or average annual availability	[12,31]
Primary energy ratio	[24,34,35]
Energy intensities of the industrial, household and commercial level (e.g. industrial, agricultural, service/commercial, household and transport energy intensities)	[3,20]
Energy balance	[19,42]
Social C&I:	
Job or employment creation or opportunities	[7,8,12,17–20,24,25,27,28,30,31,35]
Job income or working conditions	[12,19,20,39]
Access or rights to use land, water and other natural resources	[19,39]
Food security in the context of bioenergy generation and biofuel supply	[19,39]
Decision-making, participation, responsibility, confidence or empowerment as well as planning, management or monitoring	[17–19]
Wider social C&I (e.g. respect for human rights and minorities, standard of living)	[19,39]
Accessibility, affordability or disparities	[3,20]
Social or cultural cohesion, acceptability or benefits (e.g. social justice, effect on public spending, social impacts)	[7,9,17–19,24]
Compliance with laws	[19]

The identified C&I (Table 1), which built the basis for the case study's C&I pre-selection (3.3), are also divided in these four categories following the alternative ordering of "environmental", "economic", "technical", and "social" aspects.

In sustainable energy decision making it can be observed that 'CO_2 emission' and 'Investment cost' are the most common environmental and economic aspects, respectively [24]. Furthermore, 'Efficiency' is the most common technical criterion to evaluate energy systems according to Jovanović et al. [20] and others [8,24–29] and in their evaluation of the impacts of power plants, Chatzimouratidis and Pilavachi [30] state that in the energy sector, 'Job creation' is considered as the key social aspect used for sustainability assessments.

It can be concluded that the vast number of C&I makes it imperative to take a systematic approach to select C&I for individual projects or case studies. A systematic approach using requirements for C&I selection is described in the subsequent sections of this paper.

2.2. Requirements for criteria and indicators selection from literature

Requirements for C&I selection enable a 'filtering process' as mentioned previously. These requirements can be found in literature about the sustainability assessment field in general, as well as about the energy and bioenergy fields particularly. These types of literature were considered in order to select the most appropriate set of requirements.

2.2.1. Requirements for C&I selection: sustainability assessment field

Requirements for sustainability C&I selection have been widely described in literature about sustainability assessment in general. Graymore et al. [16] used three 'filters' ensuring: (a) C&I relevance to the region, (b) consideration of both trend and condition (time dynamic C&I) and (c) consideration of the relationships between C&I to avoid an isolated perspective on C&I. First, they asked stakeholder organizations and community representatives to select most suitable C&I from a set of pre-identified C&I considering regional relevance (first filter). Then, the researchers filtered the remaining C&I with respect to practicality and reliability and GIS software applicability (second filter). Finally, based on this reduced set of C&I the third filter took relationships and indicator independencies into account to develop a small number of highly influential C&I.

Singh et al. [21] provide the following dimensions of C&I measurements: (a) sustainability aspect, (b) technique/method

employed (quantitative/qualitative, subjective/objective, cardinal /ordinal, one-dimensional/multidimensional), (c) type of comparison (across space (cross-section), time (time-series) or in an absolute/relative manner), (d) input ('means') or output ('ends') focus, (e) clarity and simplicity, (f) data availability across time and space, (g) flexibility (e.g. for change). These dimensions rather help to classify and evaluate C&I measurements than to select appropriate C&I. However, since they address C&I measurements, they can be summarized into the requirements practicality, simplicity and reliability, whereas the latter covers the reproducibility of assessment results.

According to Baker et al. [45] C&I should be: (a) able to discriminate among alternatives, (b) complete in regard to all goals, (c) operational and meaningful to understand the impacts of the alternatives, (d) non-redundant and (e) few and manageable in number. In other words C&I should measure important issues, comprehensively and in a meaningful way, hence they should be relevant keeping the problem's goal in mind. Comparability must be ensured, as well as a high degree of independency of C&I. The notion that C&I should be few in number to increase understandability is rather an overall requirement than an individual selection requirement to decide, whether or not a criterion and its indicator(s) should be chosen.

For another project [46] sustainability C&I were selected and at a later stage reviewed by stakeholders based on the following specifications: (a) comprehensiveness, (b) applicability to each alternative, (c) transparency, (d) tractability of data, and (e) practicability with respect to available time and resources. The first two specifications can be summarized into the requirement relevance and the last two into practicality. Transparency is described as the stakeholders' ability to understand C&I or in other terms it describes the simplicity of C&I. This simplicity of C&I is also emphasized by Olsthoorn et al. [11] (p.457) who suggest as a general guideline that C&I "should be as simple as possible and only as complex as necessary".

Gilmour et al. [18] interviewed key stakeholders individually to verify and refine pre-selected C&I with reference to the specific drivers, aspirations and objectives of a specific sustainable waterfront development. In this process each criterion and its indicator (s) were addressed to verify relevance.

Another participatory approach was taken by Fraser et al. [10] who held community focus group meetings to rank C&I according to their perceived accuracy and ease of use. These two requirements refer to practicality and simplicity of C&I, respectively. C&I can also be selected by simply considering the availability of data, i.e. the practicality of C&I can be regarded as the single requirement [13].

Lattimore et al. [2] in their paper about sustainable wood fuel production outline that C&I should be as broadly applicable as possible and be imbedded within a framework of local adaptability. Furthermore, they identified C&I based on comprehensiveness and effectiveness. These aspects can be covered by the requirements practicality and relevance.

2.2.2. Requirements for C&I selection: energy and bioenergy sectors

Apart from literature about sustainability assessments in general, requirements for C&I selection have also been described in literature specific to the fields of energy and bioenergy. In a survey about sustainability C&I for bioenergy systems [19], experts were asked to rate C&I according to relevance, practicality, reliability and importance. Since determining the importance of C&I is typically covered by separate decision making processes (e.g. [47–49], this requirement was excluded for further considerations in the C&I selection process described in this paper. C&I relevance is the first requirement described and refers to relevance in regard to the concept of sustainable bioenergy systems, as well as the contribution of this aspect's assessment to an improved understanding of the sustainability context. In terms of practicality, experts were asked in the case study described by Buchholz et al. [19] to consider, whether existing scales and/or measurement units and measureable threshold values exist for the individual C&I. In addition, the ease of obtaining data and measuring C&I in a cost, time and/or resource effective manner are mentioned attributes for this requirement. How reliable C&I assessment results are and whether these results can be reproduced, are considerations in regard to the reliability requirement. Further considerations for this specific requirement are: high uncertainty attached to C&I and the ease of reaching consensus.

Wang et al. [24] state that C&I development and selection requires parameters associated with reliability, appropriateness, practicality and limitations of measurement. In this context, appropriateness refers to C&I relevance and limitations of measurement could be part of the practicality requirement for C&I. In general the authors share the opinion that a low quantity of C&I is beneficial to the evaluation of energy systems process. Furthermore, they establish principles for decision-makers to select C&I. The following principles are suggested: (a) consistency, (b) independency, (c) measurability, (d) comparability. The first principle suggests consistency with the decision-making objective and therefore relevance. The independency principle demands a criterion and its indicator(s) to be excluded, if an inclusion relationship at the same level exists. Furthermore, a criterion and its indicator(s) should allow reflection of the alternatives' performances from a different perspective. The third principle requires C&I to be quantitatively or qualitatively measurable and hence to be practical. Finally, the comparability principle should ensure distinction between alternatives, whereas it also suggests normalization processes to compare between C&I results.

In a paper about sustainability indicators in the electricity sector [12] 15 selection requirements are grouped under three major topics: (a) conception, (b) application and (c) consistency. The first requirement in the group 'conception' is adhesion, which is about a direct relationship of C&I to the analyzed aspect. This requirement could fall under the relevance requirement. Feasibility and validity, the next two requirements in this group comprise of aspects covering practicality or reliability issues of C&I. With respect to practicality, data availability and the feasibility of additional data collection is also outlined in a paper, which provides energy indicators for sustainable development [3]. The requirement clarity in Rovere et al. [12] is subject to the group's last requirement simplicity. In the next group 'application' the requirements: sensitivity and temporality and ease cover the practicality aspect of C&I, because they represent their ability for trend and temporal analyses and the difficulty level of their practical application. The spatiality requirement covers comprehensiveness of C&I and hence their relevance. The remaining requirement in this group is reliability and is described as the ability to capture both, positive and negative issues in an unbiased manner. In the final group 'consistency' the requirement discernment reflects an aspect of comparability, whereas equilibrium refers to the independency of C&I. Additionally, the requirement verifiability comprises of the capacity of C&I to reproduce data and therefore addresses an aspect of reliability. Relevance is separately represented in this group as the remaining requirement. This requirement is also addressed in a paper about technological energy priorities and the multi-criteria decision-making approach [25], in which the problem's formulation, a country's specific energy characteristics, as well as its development needs and perspectives are considered as determinants influencing C&I and their performances. These determinants could be summarized into the relevance requirement.

3. Application of methodology in case study area

3.1. Scenario description

Two scenarios, 'A1-2' and 'A3-4', each with a centralized and a decentralized bioenergy strategy for the Scottish Region Tayside & Fife were developed (Table 2). However, the scale of energy generation differed between the scenarios, as well as the alternatives. For both of the first scenario's alternatives the total electrical outputs were assumed to be 100 MWe. Also, a second scenario with 10 MWe electrical outputs for each of this scenario's alternatives was developed. For this second scenario the diversifying parameters and hence the complexity level of comparison was significantly reduced by assuming the same source and type of fuel to be used for both alternatives. The reason for using these specific scenarios and alternatives for the research case study was to allow the decision making process to be independent not just from the scale of the bioenergy developments, but also from the complexity level of the comparison. In other words by establishing and presenting to bioenergy experts scenarios with varying levels of differences in specifications – one in which all specifications differ and one in which only a single specification distinguishes the two alternatives – the decision making processes were less influenced by the complexity of the comparison. Furthermore, the presented range of scenarios and alternatives was intended to demonstrate the broad application potential of this participatory approach to select sustainability C&I in the bioenergy field.

3.2. Requirements for C&I selection for case study

Based on the literature review described previously (Section 2.2), the final set of requirements for C&I selection for the case study was chosen as shown in Table 3. Each requirement was described for clarification based on the literature review. In line with this set of requirements, C&I were pre-selected first and then presented to regional bioenergy experts to decide which sustainability C&I should be employed for the case study.

3.3. Pre-selection of C&I for case study

Based on the identified sustainability C&I (Section 2.1) and the selection requirements (Section 2.2), a number of sustainability C&I were pre-selected prior to presenting the resulting C&I short-list to regional bioenergy stakeholders to reach consensus on them. For this step the case study scenarios as described previously had to be kept in mind at each stage of the process. The process consisted of a series of sorting steps before the most appropriate C&I were chosen.

First, C&I from literature were sorted by the four categories: environmental, economic, technical and social. As a second sorting step, the C&I were summarized, resulting in the following classification:

- Environmental: GHG Emissions, Air Quality, Water, Waste and Other Environmental C&I.
- Economic: Economic Viability, Regional Energy Self-Sufficiency and Other Economic C&I.
- Technical: Efficiency, Technology, Other Technical C&I.
- Social: Regional Job Creation, Energy for Households, Employment Conditions, Regional Food Security and Other Social C&I.

At this point it became apparent that some C&I were redundant and others could be classified in more than one category. For example, due its nature and potential effects on both aspects, C&I related to fuel and resource availability and import dependency can either be in the economic or in the social category. C&I definitions, if

Table 2
Case study scenarios and alternatives.

Alternative	Total electrical output (MWe)	Strategy		Type of fuel	Source of fuel
Scenario 1					
A1: Large-scale bioenergy plant (predominantly for electricity generation)	100	Centralization strategy	Single location	Woody biomass	Predominantly from abroad
A2: 20 Medium-scale bioenergy combined heat and power (CHP) plants	100	De-centralization strategy	Multiple locations	Any biofuel (and related technologies)	Predominantly regional sources
Scenario 2					
A3: Medium-scale bioenergy combined heat and power (CHP) plant	10	Centralization strategy	Single location	Any biofuel (and related technologies)	Predominantly regional sources
A4: 10 Small-scale bioenergy combined heat and power (CHP) plants	10	De-centralization strategy	Multiple locations	Any biofuel (and related technologies)	Predominantly regional sources

Table 3
Requirements for C&I selection for the case study.

Requirement for selection:	Description:	Source:
Relevance:	How relevant are the criterion and its indicator(s) for decision-making for sustainable bioenergy developments? Does the assessment contribute to a better understanding of the sustainability of bioenergy developments?	[2,12,16,18,19,24,25,45,46]
Practicality:	Do scales and/or measurement units exist? Can data easily be obtained and measured in a cost, time and/or resource effective manner?	[2,3,10–13,16,19,21,24,46]
Reliability:	How reliable/reproducible are the assessment results? Is there a high uncertainty attached to the assessment results?	[12,16,19,21,24]
Independency:	Are the criterion and its indicator(s) independent enough, i.e. do they reflect the performance of alternatives from a different viewpoint or do they duplicate other C&I?	[12,16,24,45]
Comparability:	Are the criterion and its indicator(s) able to discriminate among alternatives and do they support the performance comparison of alternatives?	[12,24,45]
Simplicity:	Are the criterion and its indicator(s) easy to understand by all stakeholders?	[10,21,46]

available from the reviewed papers, were of assistance to eliminate redundant C&I or to aggregate similar C&I such as 'Soil Protection' and 'Soil Quality' or 'Job Creation', 'Employment Generation' and 'Contribution to Employment Opportunities' Creation'. This process was characterized by selecting the most case-study relevant criterion and indicator to represent similar aspects (e.g. 'Air quality' and the indicator 'Non-GHG Emissions'). In this procedure the six requirements for C&I selection as defined in Table 3 were also considered. For example the indicator 'Net Present Value' was selected to represent 'Economic Viability', because cost indicators such as 'Investment Cost' were basically included in the calculation of that indicator. At this stage, C&I were also modified or new C&I were developed to take account of topical issues, which were felt to be not or not fully addressed in the reviewed literature such as for example the indicator 'Threat for Food Security', which emphasizes and combines issues in regard to food security and land conversion caused by biofuel plantation. These topical issues were typically characterized by a high relevance in regard to decision-making for sustainable bioenergy developments at the time when the case study was undertaken. Also, in order to add more case-study-specific relevance, indicator units were modified (e.g. 'Created Jobs/kW h (plant and supply chain specific)' for the criterion 'Job Creation'). Based on these changes the final C&I descriptions were developed. By again comparing each of the C&I against the six requirements for selection as defined previously (Table 3), the final pre-selection of C&I was undertaken. In this process, a criterion and its indicator were assessed using a three-point scale with 'low', 'medium' and 'high' scores. The threshold score was the score 'low', i.e. if a score against a requirement was 'low', the assessed criterion and its indicator was excluded. Table 4 below illustrates the scoring results of the C&I pre-selection process:

The following two examples illustrate how C&I were scored at this pre-selection stage:

3.3.1. *Air quality*

The first scoring against the six selection requirements comprised the criterion 'Air Quality' and its indicator 'Non-GHG Emissions'. This criterion and its indicator were considered to be highly relevant and to have a high comparison level for the case study alternatives. The high score against 'comparability' was due to the quantitative nature of the criterion's indicator, which enables alternatives to be compared relatively easily. The high score for relevance was justified by the aggregation potential of the criteria, as it allows the inclusion of several emissions (NO_x, CO, SO_2 and particulates). In regard to 'practicality', 'reliability', 'independency' and 'simplicity' 'medium' scores were assigned. Although, often measured for projects of this type, the indicator 'Non-GHG emissions' and its mentioned aggregation potential was regarded as causing potential limitations in regard to the first two requirements, because data availability and reliability of all the case study's emissions was assumed to be incomplete or limited. Aggregation was also the reason for the medium score for 'simplicity', because multiple data for one indicator was regarded as influencing negatively the understandability of the criterion and its indicators for all bioenergy experts. The criterion and its indicator are influenced by several other C&I and thus a 'medium' score was assigned to the requirement 'independency'.

3.3.2. *Regional food security*

The criterion 'Regional Food Security' with its indicator 'Threat to Food Security' scored 'high' against 'relevance', because this aspect was related to both, the topical food versus-fuel-controversy, which covers the issue of diverting farmland or crops for biofuels production in detriment of the food supply, as well as the already existing and predicted increase in competition for biofuels resources in the case study area. It was assumed that it would be difficult to obtain and measure data in a cost, time and/or resource effective manner and predictive data would rather be uncertain, due to the early stage of energy crop plantation in Scotland. Hence, for both requirements 'practicality' and 'reliability' 'medium' score were assigned. The criterion is influenced by other C&I and scored 'medium' against 'independency'. The criterion allows discrimination among the scenarios' alternatives and therefore scored 'high' against 'comparability'. For the last requirement 'simplicity' it was assumed that not all experts would easily understand the criterion and its indicator, which was reflected in a 'medium' score.

Table 5 below illustrates the pre-selected C&I. This table was presented to bioenergy experts for the final selection process:

3.4. *Final selection of criteria and indicators by experts in case study area*

Similar to other studies in the sustainability and bioenergy sector [19,50], participants of the multi-stakeholder forum were bioenergy experts rather than members of the general public and like in Sheppard and Meitner [1] were selected based on their knowledge and expertise in the subject, their history with planning processes and based on how much they would be affected by

Table 4
Scoring results of the C&I pre-selection for the case study.

Category	Criterion	Indicator	Relevance	Practicality	Reliability	Independency	Comparability	Simplicity
Environmental	**Air quality**	Non-GHG emissions	High	Medium	Medium	Medium	High	Medium
	GHG emissions	CO_2 emission	High	Medium	Medium	Medium	High	High
	Water	Water management	Low	Medium	High	Medium	High	High
	Waste	Waste re-processed	High	Medium	Medium	Medium	High	High
	Others	Others	N/A	N/A	N/A	N/A	N/A	N/A
Economic	**Economic viability**	Net present value	High	Medium	Medium	Medium	High	Medium
	Regional energy self-sufficiency	Fuel import dependency	High	Medium	Medium	Medium	High	Medium
	Others	Others	N/A	N/A	N/A	N/A	N/A	N/A
Technical	**Efficiency**	Energy efficiency	High	High	High	Medium	High	High
	Technology	Knowledge of the technology	High	Medium	Medium	High	High	Medium
	Others	Others	N/A	N/A	N/A	N/A	N/A	N/A
Social	**Regional job creation**	Job creation	High	Medium	Medium	Medium	High	High
	Energy for households	Number of households supplied	Low	Low	Low	Medium	Medium	High
	Employment conditions	Average level of job income	Low	Medium	High	Medium	Medium	High
	Regional food security	Threat to food security	High	Medium	Medium	Medium	High	Medium
	Others	Others	N/A	N/A	N/A	N/A	N/A	N/A

Table 5
Pre-selected C&I for the case study.

Category	Criterion	Indicator	Unit	Description
Environmental	**GHG emissions**	CO_2 emissions	kg/kW h (supply chain specific)	Emissions of CO_2 across bioenergy supply chain
	Air quality	Non GHG-emissions	kg/kW h (operational plant specific)	Emissions of NO_x, CO, SO_2 and particulates from operational bioenergy plant(s)
	Waste	Waste re-processed	% of Scottish waste re-processed to fuel (per annum)	Waste re-processed to fuel for bioenergy production
Economic	**Economic viability**	Net present value	£/kW h (operational plant specific)	Expected incoming and outgoing cash flows derived to present economic values to enable a comparison independent of time
	Regional energy self-sufficiency	Fuel import dependency	% of imported feedstock (operational plant specific) (per annum)	Percentage of imported feedstock for the bioenergy plant(s)
Technical	**Efficiency**	Energy efficiency	% (operational plant specific)	Expresses the technology's ability to convert the primary energy source to energy
	Technology	Knowledge of technology	% (worldwide)	Represents the technology's maturity rate, as well as its uptake/adoption in the international market
Social	**Regional job creation**	Job creation	Created jobs/kW h (plant and supply chain specific)	Number of direct and indirect jobs created at the bioenergy plant(s) and along the Scottish bioenergy supply chain
	Regional food security	Threat to food security	% of total arable land used for energy crop plantation	Reflects the availability of remaining arable land for food production in Scotland

the scenarios' alternatives. It was ensured that all interests and aspects of sustainability in the field were covered by equal proportions of participating representatives from different backgrounds, which as outlined by Voinov and Bousquet [51] was also intended to increase public acceptance and credibility of the forum's outcomes. A relatively balanced composition of participants from local authorities, the regulative body, the business support agency, environmental protection, harvesting and supply, sawmilling, bioenergy production, agriculture, forestry and waste management was achieved by nonproportional quota sampling [52]. In total 13 regional bioenergy experts participated in the multi-stakeholder forum.

The invited participants were asked to reach consensus about the final set of sustainability C&I for the case study scenarios and alternatives. It was explained that the selection of the most appropriate C&I is crucial to assess sustainability, because any aspects not included would simply be ignored from the decision making process, which again would influence assessment results.

First, a PowerPoint™ slide explaining the four distinct aspects within sustainability that interrelate – environmental, economic, social and technical – was presented to the participants of the multi-stakeholder forum. After highlighting the goal of the multi-stakeholder forum (consensus about C&I selection) and explaining the procedure, the requirements for C&I selection along with their descriptions (see Table 3) were presented on another PowerPoint™ slide, of which also hard-copies were handed out. The experts were explained that those six requirements were used for pre-selection and asked to make their own selection choices also based on them. Furthermore, presented slides with problem hierarchies for both scenarios allowed participants to keep an overview of the relationships between the goal, categories, criteria and alternatives (see Fig. 1 as an example).

The pre-selected C&I (Table 5) were presented to the participants grouped by sustainability aspect. First, questions were answered and issues were clarified in regard to C&I descriptions. Then, the process of final C&I selection itself was carried out by directly asking the forum participants to reach consensus about the suitability of each pre-selected criterion and its indicator to assess the case study's scenarios and alternatives. The participants were encouraged to confirm or make changes to the presented set or propose new C&I, again by taking account of the defined six requirements for selection. In cases when consensus about pre-selected or newly proposed C&I could not be reached, the C&I were regarded suitable, when there was evidence that a significant majority of forum participants agreed on them. To keep track of the communication notes were taken during and after the event.

4. Results and discussion

The processes of the pre- and final selection of C&I are discussed in the following.

4.1. C&I pre-selection process

When reflecting on the pre-selection process it can be observed that all pre-selected C&I scored 'high' against the requirements 'relevance' and 'comparability'. The reason for that was that throughout the process the case study scenarios and alternatives were kept in mind. In other words, the steps including sorting and classification, modifying of indicator units and the final descriptions of C&I contributed to increased 'relevance' and 'comparability' of those C&I. Scoring against the requirements 'practicality' and 'reliability' was highly subjective, because the scores were based on the most assumptions and uncertainties in regard to data gathering, measuring and reliability. When scoring some C&I against those requirements, location-dependent levels of data availability and quality had to be considered, which added more complexity to the scoring processes. In this connection it had to be kept in mind, that the described scoring processes had the sole purpose to pre-select C&I. As described previously, participants of the multi-stakeholder forum had the opportunity to confirm, change or propose new C&I resulting in a final set. When scoring 'simplicity' of C&I, the groups/organizations and positions/departments of the participants invited to the multi-stakeholder forum were taken into account. However, the assumptions made when scoring C&I against this selection requirement can still be regarded as highly subjective, because knowledge and understanding of C&I first and foremost depend on personal backgrounds of individual forum participants.

4.2. Participatory selection of environmental C&I

In the multi-stakeholder forum, in which the final C&I took place, participants suggested that C&I covering biodiversity and visual impacts of potential plant(s) could be included. However, after a discussion the forum participants ruled these aspects out, because of the research's scope and focus on supporting sustainability decision-making to screen and assess location areas, rather than specific site locations, for which these aspects are typically assessed. For the same reason, the suggestion of the regulator's representative to look at the supply chain, including road transport of fuel when assessing the

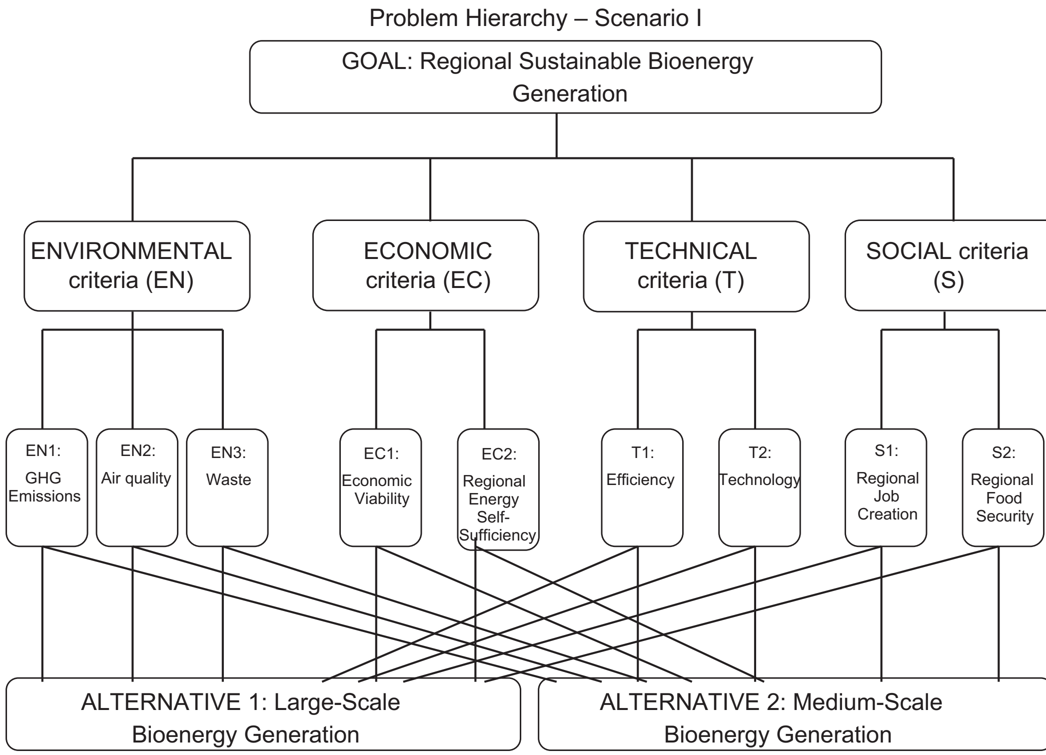

Fig. 1. Problem hierarchy for scenario 1.

criterion 'air quality' was not found suitable. Thus, it was agreed that although assessing the three aspects is important, this would have to be carried out after identifying concrete plant locations.

Contrary to that the criterion 'GHG emissions' and its indicator 'CO_2 emissions' were confirmed by the majority of the forum participants, although it includes assessment of CO_2 emissions across the Scottish supply chain. Forum participants from the environmental protection organization and the bioenergy producers highlighted that when assessing this criterion and its indicator the bioenergy supply chain has to be defined by keeping the goal of the decision making problem, its scenarios and alternatives, as well as the 'Life Cycle Assessment' (LCA) approach and the EU Commission's 'Report on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling' [53] in mind. It was also proposed and agreed by most experts to extent the scope of the indicator to 'CO_2—equivalent GHG emissions'.

Suggestions for change and improvement were also made for the criterion 'waste' and its indicator 'waste re-processed'. Although acknowledging the potential for Greenhouse Gas (GHG) emissions savings, the forum participant from the large scale bioenergy producer questioned the economic viability of re-processing waste materials into biofuel. On the other hand, the participant proposed to introduce an indicator to measure residual ash usage, on which the forum's participants agreed. However, in terms of re-processing waste materials into biofuel, most of the forum participants argued that its use would be the individual business decision of the bioenergy producer and that the economic success of waste re-processor companies in Scotland demonstrated that waste re-processing can be profitable. In principle, it could be assumed that the reasoning of the forum participant representing the large-scale bioenergy producer was motivated to a certain extent by the organization's plans to build a large-scale bioenergy plant in the research case study area in the future. For this plant it is planned to utilize only small amounts of re-processed waste as fuel and to put processes in place to make residual ashes useable.

Also covering the waste aspect, a forum participant from a business support organization brought forward that the indicator and its description could be more specific in terms of waste type and pointed out that in re-processing waste different classifications and regulations for various materials have to be kept in mind. However, it can be argued that breaking-down the several re-processed waste types could become relatively complex and less practical compared to measuring a single indicator, which accumulates all types of re-processed waste. This is particularly true when taking into account that for three of the four alternatives of the case study scenarios utilization of any type of biomass feedstock and related technologies was possible. For this reason, the criterion and its indicator were not changed.

4.3. *Participatory selection of economic C&I*

The forum participants from a sawmill, a bioenergy producer and a business support organization raised concerns about the availability of biomass feedstock supplies and the increasing dependency on biofuel imports. They also made aware of possible consequences of not securing alternative, sustainable supply sources. Therefore, along with the substantial majority of the other experts, they agreed on the particular usefulness of the proposed criterion 'regional energy self-sufficiency' and its indicator 'fuel import dependency' covering this aspect.

Moreover, in addition to the pre-selected economic C&I two new aspects were suggested to be incorporated during this stage of the multi-stakeholder forum. One aspect was about covering future economic incentives for the bioenergy sector and the other aspect about addressing the level of regulations for the different alternatives of the case study scenarios. However, it was found that both proposed aspects are directly or indirectly covered by the pre-selected criterion 'economic viability' and its indicator 'net present value (NPV)', as they either generate additional income or result in costs to maintain or put measures into place to comply with regulation.

Table 6
Final set of selected C&I for the case study.

Category	Criterion	Indicator	Unit	Description
Environmental	**GHG emissions**	CO_2-equivalent GHG emissions	kg/kW h (supply chain specific)	CO_2-equivalent GHG emissions across bioenergy supply chain
	Air quality	Non GHG-emissions	kg/kW h (operational plant specific)	Emissions of NO_x, CO, SO_2 and particulates from operational bioenergy plant(s)
	Waste	Waste re-processed	% of Scottish waste re-processed to fuel (per annum)	Waste re-processed to fuel for bioenergy production
Economic	**Economic viability**	Net present value	£/kW h (operational plant specific)	Expected incoming and outgoing cash flows derived to present economic values to enable a comparison independent of time
	Regional energy self-sufficiency	Fuel import dependency	% of imported feedstock (operational plant specific) (per annum)	Percentage of imported feedstock for the bioenergy plant(s)
Technical	**Efficiency**	Energy efficiency	% (operational plant specific)	Expresses the technology's ability to convert the primary energy source to energy (electricity and/or thermal energy) for usage
	Technology	Knowledge of technology	% (worldwide)	Represents the technology's maturity rate and its uptake/adoption in the international market, which reflects the technology's reliability
Social	**Regional job creation**	Job creation	Created jobs/kW h (plant and supply chain specific)	Number of direct and indirect jobs created at the bioenergy plant (s) and along the Scottish bioenergy supply chain
	Regional food security/ Change of landscape and land use	Land use change	% of total productive land use change in favour of energy crop plantation	Reflects the change of landscape and land use due to energy crop plantation and the availability of remaining productive land in Scotland

Representatives of a bioenergy producer and a business support organization further suggested that economic C&I covering risk could be considered. They argued that this would address the risks arising from technical failure and biofuel supply bottlenecks. However, it can be argued that these risks are already indirectly or directly addressed by the pre-selected criteria 'regional energy self-sufficiency' and 'technology' and their respective indicators 'fuel import dependency' and 'knowledge of technology'. Therefore, these suggestions for change were not further considered.

4.4. Participatory selection of technical C&I

The two representatives of the bioenergy producers in the multi-stakeholder forum outlined that the technical criterion 'efficiency' and its indicator also cover economic issues and could therefore categorized as either technical or economic C&I. Furthermore, they stated that the criterion could be renamed to 'energy productivity' to address more the possible shared use of generated heat, for instance for district heating, for some alternatives of the case study or, alternatively, the description of this criterion and indicator could be clearer. After the multi-stakeholder forum, it was decided that based on the common use and the definitions found in literature, the criterion and its indicator remains in the technical category and renaming would not be required for the case study. However, in order to clarify what is meant by the criterion and its indicator the description was amended.

Furthermore, a forum participant representing a bioenergy producer further proposed that the description of the criterion 'technology' and its indicator 'knowledge of technology' should be improved, as this aspect basically measures how save and reliable a technology is.

4.5. Participatory selection of social C&I

Again with respect to the supply situation, the forum participants from an environmental protection organization and a sawmill, suggested to take account of business and jobs taken away from large traditional industries in the case study area, which compete for the same biofuel supplies as the bioenergy industry, such as the wood panel industry. However, it was argued that availability of supplies would just be one of many factors influencing the development of this competitive market. Based on this argument, the majority of experts agreed that no practical and measurable criterion and its indicator would cover the issue appropriately.

Another forum discussion followed with forum participants from the environmental protection organization, a local authority, a bioenergy producer and a forestry support organization suggesting that land use or landscape change caused by energy crop plantation could be addressed. As indicators 'marginal price for farmers to switch to biofuels' and 'use of marginal land' were proposed. However, the substantial majority of forum participants agreed that these indicators would be relatively specific and that the pre-selected criterion 'threat to food security' with its indicator and unit '% of total arable land used for energy crop plantation' principally already covers the aspect for the given scenarios appropriately. By renaming the criterion and indicator, as well as by amending the unit and description, this was made more transparent and understandable.

4.6. Final set of selected C&I

In summary the set of pre-selected C&I (Table 5) was confirmed to be appropriate by a substantial majority of the participants with the exception of the mentioned relatively minor changes or modifications of four C&I. Principally, the effectiveness of the pre-selection process was underlined by the few changes. Even in cases where no changes would be suggested by experts or other stakeholders in similar research or decision making situations, as mentioned, following a participatory approach is vital to ensure acceptance, transparency and credibility throughout the decision making process. Furthermore, this approach encourages ownership at a local level, which can be crucial when it comes to the implementation phase of bioenergy developments, as local ownership could increase stakeholder acceptance leading to a higher probability of project approval and time savings. Although related to identified C&I such as 'participation' and 'empowerment' (Table 1), 'local ownership', as well as 'regional equity' also could be considered as separate C&I for future research particularly focusing on decentralized and centralized bioenergy generation. Further notable is that qualitative C&I were not suggested in the multi-stakeholder forum, which is in line with the arguments brought forward previously (Section 3.3). Table 6 illustrates the final set of selected C&I for the case study with the changes highlighted. In principle, it remains to be seen whether the selected

C&I can successfully be employed for decision making processes, if the described scenarios and alternatives were implemented in the case study area or in similar regions. This could be a subject for future research.

5. Conclusions

This paper provides a generic approach for selecting sustainability C&I for bioenergy developments by using a participatory methodology. Selecting appropriate C&I to assess the sustainability of a project or development is crucial and significantly influences the assessment results.

In principle, the methodology consisted of two processes, a pre-selection of suitable C&I by the researchers and a final selection by regional bioenergy experts in a multi-stakeholder forum. The methodology was applied in a Scottish region (Tayside & Fife).

Although the participants of the multi-stakeholder forum regarded the resulting set of C&I as being suitable, it remains to be seen whether the selected C&I can successfully be employed for decision making processes, if the described scenarios and alternatives were implemented in the case study area. However, this set of C&I can serve as a benchmark set in this and similar decision making situations. For that purpose the case study's two scenarios and four alternatives were deliberately developed in a rather generic way allowing a wide range of application potential within the energy and particularly the bioenergy field. For similar research or decision making situations this particular set of C&I can be used as a starting point for C&I pre-selection prior to regional bioenergy stakeholders or wider stakeholders making final C&I selection decisions on a case-to-case basis.

Furthermore, the literature reviews to identify relevant C&I and requirements for C&I selection provide a broad application potential to assist C&I selection, as the sustainability field in general, the energy sector and the bioenergy sector in particular are covered. The same applies for the methodology itself. Although, for other research or decision making situations different C&I may be relevant, the presented approach to systematically select C&I and to justify this selection can be undertaken.

The methodology for selecting C&I can be combined with participatory C&I prioritization to determine the relative importance of each criterion and its indicator. This can help to improve performance assessments of selected C&I and support participatory decision making.

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